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ORIGINAL ARTICLES.

Some Mesozoic and Tertiary Igneous Rocks from Portuguese East Africa.

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THE very interesting igneous rocks of the Mozambique Company's territory have not had much attention paid to them in the past, though some of them were noticed in the first paper dealing with the Karroo beds near Tete, that by Lapierre.[1] That writer was in advance of some subsequent observers in his recognition of the peculiar character of the Lupata lavas: so far, indeed, have some others been from this that the various geologists working in the Tete district have actually been accustomed to call the Karroo basalts the "Lupata Volcanics", as is done in the most recent paper referring to that area.[2] The age of the basalts was demonstrated by the writer in some notes contributed to this Magazine in 1922,[3] and to establish this it was necessary to discuss the position of the Lupata lavas. Messrs. Teale and Campbell Smith subsequently published the first reliable petrographical descriptions of some specimens previously collected by the former, and the present paper is intended to supplement by further field and petrographical notes the valuable work of Dr. Teale, who has long since sought pastures new.[4] It may be mentioned that one of the chief features of the area is the way in which the various igneous rocks are sometimes intermixed. This is a leading factor in contributing to the uncertainty which surrounds the dating of some of the intrusives. Thus a large number of intrusions of various kinds traverse the Karroo basalts and these are undoubtedly of two and perhaps of three different periods. Faulting and overlaps also cause further complications, as may be seen in the small sedimentary area near Mutarara, where Tertiary, Cretaceous, and Karroo volcanics occur closely associated.

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[1] *Annales des Mines*, 1883, p. 585.

[2] B. Karpoff, *Ann. Soc. Geol. Belg.*, 1928.

[3] "Extension of the Karroo Lavas," Geol. Mag., Vol. LIX, p. 166.

[4] See especially *Trans. Geol. Soc. S.A.*, vol. xxvi, 1923, pp. 103–59. Also Teale and Campbell Smith, Geol. Mag., vol. lx, 1923, pp. 226–37.

Periods of Eruptive Activity.—To give a clear idea of the evidence for the age of the lavas and intrusions of the Zambesi Valley and the country generally to the south of it, it is necessary to set out briefly the salient points of the geology of the region where they occur. Near the Anglo-Portuguese border the ancient rocks of the Rhodesian plateau are met with in most places, though in the south there are pre-Karroo sediments which it is not proposed to discuss here, though it may be remarked that they also include a volcanic series seen near Spungabera in the Mosurise district. Nearer the coast there is an area of sedimentary rocks which expands north and south of the Beira and Mashonaland railway until in both the Zambesi and Sabi valleys it stretches right across the Mozambique Company's territory. The writer has seldom spent less than two or three months doing field work in this region during each year from 1921 onward, while during 1927 and 1928 he had the able co-operation of Mr. J. C. S. van Soelen, who not only examined certain areas in great detail but made valuable topographical observations which assisted greatly in clearing up certain points. The brief outline given in this magazine in 1922 has been fully borne out by subsequent work and it may be noted that only the mapping of a large area could provide the necessary evidence to establish conclusively the pre-Tertiary age of the Lupata volcanic series. Along the Zambesi itself where these volcanics actually occur the marine Tertiary strata first recorded on the Sheringoma plateau by Messrs. Teale and Wilson[1] do not appear, and although north-east of Chemba there is a long stretch of presumably Tertiary sands and gravels, probably connected with the early history of the Zambesi itself, these merely serve to obscure the position. By proceeding southward, however, from the Lupata Gorge, the Karroo basalts and the overlying Lupata series can be traced continuously to where they pass under the Sena sandstones, which can also be followed eastward without a break to Sena from the same point. Further south still these latter pass under the Urema syncline on the eastern edge of which the highly fossiliferous Chalk of the Upper Cretaceous is well seen at several points in spite of the overlap of the Upper Tertiary Inyaminga grit. Beyond the fault which intensifies the depression caused by this fold the oyster bed, with its highly characteristic *Alectryonia ungulata*, which marks the base of the Chalk, is brought up in the Inyaminga anticline, where boring operations have proved below it a thickness of 2,500 feet of sandstone, greensand, clay, etc., belonging to the Sena series. The Chalk has been shown by careful measurements to have a total thickness of about 550 feet: its upper portion comprises beds of

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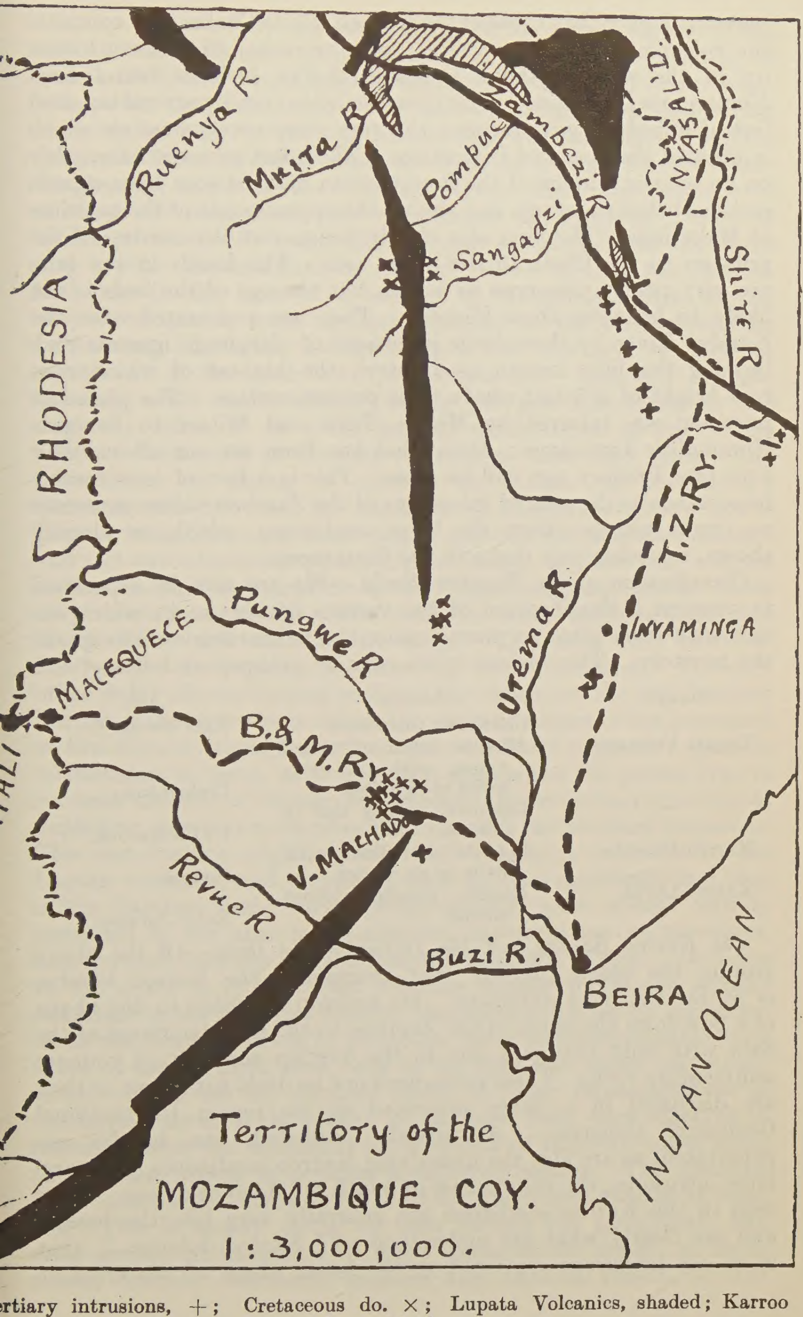
[1] In the *Geographical Journal* of 1916.



ertiary intrusions, +; Cretaceous do. ×; Lupata Volcanics, shaded; Karroo lavas, black.

horizons higher than those of the English White Chalk. To complete the volcanic history of the region it is necessary to go even higher up in the scale. Above the soft chalky beds is found hard Nummulitic Limestone. This is succeeded in turn by several hundred feet of unbedded grits forming the very steep escarpment on which is situated the Boma of Inyaminga. These last rest unconformably on an uneven surface of the limestone as may be seen from stream sections below the scarp, and also on the opposite side of the anticline at Makaringa. Mapping also clearly brings out the overlap of the grits on to the Chalk in the latter area. The fossils in the grits are very poorly preserved as a rule, but the age of the beds is not likely to be older than Pliocene. They are penetrated near the Kundwi River by three large intrusions of ultrabasic igneous rock forming the hills known as Inkweri, the highest of which rises to a height of 375 feet above their present surface. The period of intrusion was inferred by Messrs. Teale and Wilson to be post-Nummulitic Limestone: from what has been set out above their very late Tertiary age will be clear. This is a fact of considerable importance as the related intrusions of the Zambesi valley penetrate no strata younger than the Sena sandstones, which, as already shown, are some way down in the Cretaceous.

Classification of the Eruptive Rocks.—We are now in a position to attempt a classification of the various igneous rocks which are met with from place to place among the sedimentaries throughout the territory. The various types may be grouped as follows:—

Group.	*Character.*	*Age.*
—	Ultrabasic Intrusions.	Late Tertiary.
Lupata Volcanics.	Alkaline lavas of varied types, with an early series of rhyolites.	Cretaceous.
—	Dolerites, usually rich in olivine.	(?) Cretaceous.
Karroo Dolerite	Dolerite intrusions with little or no olivine.	Jurassic.
Karroo Lavas.	Basalts, usually without olivine.	Early Jurassic.

The Karroo Basalts and the Intrusions in them.—Of the above groups, the oldest, namely that comprising the Karroo basalts, is by far the most extensive. Its outcrop stretches in the shape of a bow from the north of the Zambesi to the neighbourhood of the Sabi with only two gaps due to the overlap across it of younger sedimentary rocks. These rocks need not be dealt with here, as they are discussed in a paper presented to the recent International Geological Congress. As already indicated, the basalts are penetrated, as are also the underlying Karroo sandstones, by many later intrusions, the commonest of which are dolerite dykes. Those seen in the Karroo sandstone are generally very like the basalts and are clearly what are understood as "Karroo dolerites", that is to say intrusions representing the latest phase of the eruptive activity evidenced by the outpouring of the lavas. Most of the dolerites actually seen penetrating the basalts are, however, of quite a distinctive appearance in the field and are found on examination under the microscope to be rich in olivine as a rule. That these dykes may be of post-Karroo age was suspected from the first, and later on fairly clear evidence of it was obtained near Sengasenga, south of the Pompue River. Here the presence of outcrops of decomposed basic rock caused the mapping of an area as Karroo basalt for some distance east of its limits to the north and south. Re-examination showed, however, that the igneous rock was in the form of a number of intrusions which, though very decomposed, were obviously similar to the olivine-dolerites penetrating the lavas to the west. The country, it may be mentioned, is flat with very poor exposures. Curiously enough, the only really fresh dolerite cutting the post-Karroo strata was originally taken to be a fine-grained modification of one of the alkaline Cretaceous or Tertiary intrusions that also occur, and turned out on slicing to contain no olivine. It conclusively demonstrates, however, the existence of dolerites intrusive in the Lupata sandstones, i.e. those which underlie the Lupata volcanics and rest unconformably on the Karroo basalt, of which they contain numerous derived fragments in their basal beds, and across which they overlap on to the older rocks for some miles between the Muira River and the Lupata Gorge. This does not, however, finally solve the problem presented by these intrusions. The only other richly olivine-bearing rocks of the region are the late Tertiary intrusives that have been referred to, and the largest of the intrusions in this district, though much coarser, certainly suggests a possible relationship to them, as it not only approaches the picrite type in its small amount of felspar, but appears also to contain subordinate nepheline, as seems to be often the case with the Tertiary intrusions. This last feature might equally well suggest a reference to the Lupata volcanics, and it may be regarded as a significant fact that in the Zambesi basin these olivine-dolerites seem almost entirely restricted to the area where alkaline intrusions are so numerous, namely, that between the Pompue and Sangadzi Rivers. Far away to the south it is true that precisely similar dykes are equally abundant in the Mosurise district, specimens collected by the writer along the Mosurise River in particular being indistinguishable from those of the northern area both in the field and under the microscope. There are no alkaline rocks or other representatives of the Lupata lavas in the south; or, at least, none were observed in travelling over the sediments for a stretch of fully 100 miles along their strike, which is perhaps a different matter. The question of the exact age of these dykes must for the present remain an open one. This is largely owing to their having the peculiarity, like other groups of intrusions in many parts of the world, of being almost entirely restricted, without any obvious reason, to the outcrop of one particular set of rocks, in this case the Karroo basalts. Apart from the few instances noted where these intrusions cut the Lupata sandstones near Sengasenga, a solitary example has been observed of a dyke which appears to belong to this group cutting the gneiss not many hundred yards from the margin of the Karroo basalts at Bonga, some miles south of the Muira River.

Limitations of the Comparative Method.—Before passing on, a brief digression may be made here to draw attention to the errors which may arise from ranging too far afield in endeavouring to obtain evidence by comparative methods of the age of the igneous rocks met with in various parts of East Africa. Interesting though they are from the petrographical point of view, comparisons with areas like that of the Rift Valley are often of no greater value as an indication of age than would be the application to Italy of inferences made in Sweden. The writer is personally acquainted with the volcanic areas of Kenya and Tanganyika, and has collected in them rocks that might easily have come from the part of Portuguese East Africa with which we are dealing. Stratigraphical considerations show, nevertheless, that they could not possibly be of the same age,[1] and the petrographer, though entitled to subject the evidence of the stratigrapher to rigorous criticism, must ultimately bow to his conclusions. This is particularly necessary in dealing with an area like that in which the Lupata volcanics occur. We find, in fact, that the highly alkaline types there which resemble the Tertiary volcanics of the Equatorial regions, are clearly pre-Tertiary. On the other hand, the types which are beyond doubt of Tertiary age have as their chief characteristic an ultrabasic rather than an alkaline facies. Moreover, as we have already seen, there are numerous intrusions of normal dolerite which must be grouped with either the Cretaceous or Tertiary volcanics as far as age is concerned, in spite of their quite close resemblance to, and constant association with, the Karroo basalts.

Lupata Volcanic Series.—The main development of the very interesting group of lavas that I have termed the Lupata Volcanic Series forms a crescent-shaped area which crosses the Zambesi a little above the point where that river is joined by the Muira. The latter stream also cuts across the lavas near their southern end. A smaller area of these volcanics is that near Mutarara, about 70 miles further to the east, on the north side of the Zambesi. This latter locality was first noticed by the writer in 1921, and was more closely examined by Mr. van Soelen in January of last year. It has since been visited by Dr. F. Dixey,[2] but it is not clear whether the rhyolites here occur on the horizon of the main mass of lavas at the Lupata Gorge, or on a lower one corresponding to that of the columnar rhyolite of the scarp at the entrance to the gorge, which is separated by several hundred feet of sediments from the more alkaline types.[1]

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[1] Alkaline lavas of Karroo and pre-Karroo age are now known in South Africa.

[2] See *Ann. Rep. Geol. Dept. Nyasaland* for 1928.

It is a difficult matter to summarize in a few brief notes the characters of such a varied assemblage of igneous rocks. The *rhyolites* include the immense columnar mass of the Lupata scarp, which is fully 300 feet thick, and is neither vesicular nor amygdaloidal: that it is a flow is inferred partly from its extraordinarily contorted surface, which can scarcely be explained otherwise than as the slaggy crust of a lava. Its uniformity is remarkable considering its thickness, three slices showing little variation in grain. There are no true phenocrysts and like most of the other Lupata rhyolites a leading feature is the late consolidation of the quartz. This often forms a sort of hazy background, polarizing uniformly in areas up to a millimetre across with flecks of felspar or unindividualized matter giving it a cloudy appearance like that of the cordierite in certain types of hornfels. Occasionally the quartz forms minute crescents, or rings with a cloudy centre, giving the rock a most unusual appearance. At Mutarara the rhyolites are associated with tuffs. In some types phenocrysts of anorthoclase occur and the whole mass of the rock is in certain cases made up of cloudy areas nearly a millimetre across, often with the appearance of a rude micropegmatite: it merges into what French writers call " quartz globulaire ". More stony rhyolites with flow structure are also found, as well as what may be termed *trachytic rhyolites*. These latter have quite a typical trachytic groundmass, in places nearly free from quartz, but often crowded with large and small areas of that mineral, seldom showing crystal faces, but usually rendered most irregular in shape through penetration by the felspars of the groundmass. These areas often have a micropoecilitic structure, and are sometimes so full of felspar inclusions as to have almost the appearance of micropegmatite.[2] Some specimens contain opaque moss-like aggregates which are very probably cossyrite in a somewhat altered condition: these rocks must be closely related in composition to the pantellerites. The upper lavas of the series are, as a rule, conspicuously porphyritic in the field, and seem invariably to contain nepheline, usually with a potash or potash-soda felspar in addition, but there are a few flows with no felspar at all. One of the most distinctive types is a rock we have been accustomed to call *lens-porphyry*. It forms two sheets just below the lower end of the gorge. Through the brown matrix are thickly distributed porphyritic felspars, often of an extremely perfect lens shape, usually with their long axes nearly parallel. These are commonly four or five millimetres in length, and may be regarded as highly modified rhombs of anorthoclase. This rock requires more extended microscopical and chemical investigation. Its most obvious microscopical features are the occurrence, besides the felspars, of smaller phenocrysts of grey augite and occasionally of olivine, with some equally large crystals of apatite and magnetite. These are embedded in a groundmass resembling that of a fine-grained basalt, but evidently containing nepheline as well as felspar. There is another feature, which may also be noticed in the Tertiary rocks of the Ahi Plains in Kenya: the presence of amygdale-like patches of an isotropic substance penetrated by felspar laths. These last are larger than in the rest of the groundmass, so the structure can scarcely be secondary. The isotropic mineral plays a role very like that of the quartz in the trachytic rhyolites and may be sodalite, as suggested by Prior,[1] or analcime. Several of these patches are distinctly hexagonal, though most are oval or round. There are also a few smaller crystals of a cloudy isotropic mineral which suggest nosean. The most extensively developed of the porphyries, and that which may be called *lupatite* as *the* Lupata type *par excellence*, is the nepheline-felspar-porphyry which forms two huge sheets near the lower end of the gorge. An examination of their margins suggests that they may be intrusive, an inference that is perhaps borne out by the great thickness of the more easterly and larger sheet, which must amount to 500 or 600 feet. The porphyritic nephelines may be half an inch across, while the felspars are often nearly an inch in length. The groundmass in the medium-grained varieties much resembles that of the lens-porphyry already described and contains similar rounded amygdale-like patches. The finest grained varieties have scarcely any effect on polarized light and are speckled with magnetite dust, but large crystals of apatite and magnetite occur in addition to the nepheline and anorthoclase phenocrysts. The nephelines, which show good hexagonal and rectangular sections, are fairly free from inclusions, but occasionally enclose anorthoclase (?), plagioclase,[2] augite, biotite, magnetite, apatite, and even olivine: they are somewhat clouded in patches by alteration into kaolin, zeolites, etc. The groundmass of the coarsest lupatite resembles an ordinary fine dolerite in texture: it consists of simply twinned felspar laths, greyish augite, brown biotite, apatite, magnetite, and interstitial nepheline, often with its double refraction increased by alteration into natrolite. Some slices show brown patches which may be pseudomorphs after olivine. Among the lower lavas occurring near the Fidzi River are two other very remarkable, but also, unfortunately, not at all fresh, types which may now be referred to. One is a rock showing abundant equi-dimensional porphyritic crystals of a rather yellowish greasy looking appearance. These are commonly 2 to 5 millimetres across and under the microscope often show sharply defined octagonal outlines.

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[1] Geol. Mag. Vol. LIX, 1922, p. 169.

[2] Compare G. T. Prior, *Min. Mag.*, vol. xiii, 1903, p. 242.

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[1] loc. cit., p. 241.

[2] This is the only obvious plagioclase in any of these rocks.

They are sometimes grouped in glomeroporphyritic aggregates and consist of a substance which is perfectly isotropic, and has no signs of cleavage, though turbid decomposition products are sometimes distributed through it in such a way as strongly to suggest the characteristic lamellation of leucite. It often contains numerous inclusions of orthoclase (?) and also patches of a sort of micropegmatite which seems to consist of nepheline and felspar. These have all the appearance of a replacement, as they have very irregular margins and occasionally fill the whole crystal. Though the crystals are rather pseudomorphs than the actual mineral, it can scarcely be doubted that this rock is to be regarded as originally a leucitic one, related to types like the *leucitophyre* of Rieden, Eifel, containing nepheline in the groundmass. In this case it is much decomposed but seems to have consisted chiefly of orthoclase and nepheline. The ferro-magnesian minerals are entirely replaced by ferruginous matter, carbonates, etc.: they sometimes appear as small phenocrysts, and a well-marked pseudomorph after augite is seen in one slice, while others may represent that mineral or olivine. Felspar phenocrysts are numerous, and occasionally approach in shape those of the lens-porphyry. Large grains of magnetite and crystals of apatite are abundant. Xenocrysts derived from this rock occur in patches in the overlying "lupatite", which has altered the leucites marginally into a fibrous anisotropic substance. The central parts of the larger crystals are, however, quite clear and isotropic, and it is an interesting point that they contain inclusions of apatite and magnetite but none of felspar.

Another peculiar rock among the lower lavas is a type much resembling the "lens-porphyry" in the field, except that the conspicuous felspars are of more irregular shape and point in all directions. The microstructure is altogether different: the felspars form elongated areas crowded with the pyroxene needles, nephelines, and magnetite grains of the rest of the rock, which has a brown matrix apparently of altered glassy material. The nephelines exhibit alteration into zeolitic products: a single porphyritic nepheline (1·5 millimetres) is present in the slice. A rock which considerably resembles this one in structure is the (?) Permian lava of the Knowle quarry near Crediton, Devonshire, the affinities of which have given rise to much discussion. Among the finer-grained lavas, flinty-looking types of *phonolite* are found near the top and bottom of the series. One of the lowest flows has sparse microporphyritic nephelines embedded in a groundmass of minute felspar needles and pin-points of nepheline stained with ferruginous decomposition products, together with small ill-defined prisms of what is probably aegirine-augite. Other specimens from near the Fidzi River and from the topmost flow near Mitondo have a similar groundmass except that it has abundant opaque moss-like growths of somewhat altered cossyrite, and others, smaller and even more fuzzy-looking, of a pyroxene. These rocks are extremely like some of the intrusions in the Karroo basalts: a similar intrusion occurs here cutting the topmost flow of the series. It is interesting as exhibiting that very rare phenomenon, skeleton crystals of nepheline. Two of the lowest lavas are intermediate between the types with moss-like pyroxenes and that previously described. North of the Zambesi exactly opposite the mouth of the Fidzi River is a coarsely crystalline representative of these rocks. It has laths of untwinned felspar, often a millimetre long, and correspondingly large and equally abundant altered nephelines, with much smaller brightly coloured prisms of aegirine-augite and irregular opaque patches which suggest altered cossyrite. Apatite, sphene, and magnetite are accessories. Reference may be made here to a still coarser rock which occurs alongside a mass of tuff between the Lupata Gorge and Mitondo. It is a beautiful granular red and black rock and is no doubt an intrusion, perhaps helping with the tuff to fill a volcanic neck. It may be regarded as an *ijolite,* as it consists essentially of nepheline and pyroxene in almost equal proportions. The nepheline is so altered as to be nearly opaque. The pyroxene is a greyish augite sometimes edged and terminated by true aegirine, which latter is not common in these rocks. It is deep green with a hornblende-like pleochroism, and its nearly straight extinction strongly contrasts with the large extinction angle of the augite. There is much titaniferous magnetite and abundant apatite. Neither of the two sections examined shows any sphene or melanite, minerals which are so often found in similar rocks.

Returning to the lavas, a conspicuously porphyritic type occurring in one of the uppermost flows may be described as a *phonolitic-trachyte.* It has a thoroughly trachytic groundmass of untwinned felspar laths with very little nepheline and has scattered felspar phenocrysts. The ferro-magnesian mineral is only represented by opaque decomposition products. The only really dark or melanocratic lavas occur in the upper part of the series a little below the point where the Zambesi emerges from the gorge. They include a good example of *nepheline-basalt,* which markedly resembles the large intrusive mass of Mt. Kuti, north of the Sangadzi River. The pyroxene of this rock is greyish to yellowish or greenish in colour and ranges from porphyritic crystals conspicuous in the field to fine needles in the groundmass. This comprises in addition innumerable minute nephelines and magnetite grains. There are a few partly resorbed crystals of brown hornblende, biotite, and olivine present. Apatite is a conspicuous accessory. An associated rock, not quite so dark in the field, contains plenty of felspar, as well as nepheline, in the groundmass, and the augite occurs in much stouter prisms, about 1 millimetre across: it is often grouped in glomero-porphyritic aggregates. There are some small deep brown pseudomorphs after olivine (·1 millimetre) and a number of clear areas of which some resemble the pseudoleucites previously described while others rather suggest nosean: they are often partly replaced by calcite or a brightly polarizing mineral like cancrinite. Apatite and magnetite are abundant accessories.

Before leaving the Lupata Series reference may be made to one type occurring amongst the attenuated remnant of the lavas seen in the gorge of the Muira River. The phenocrysts form a considerable proportion of the whole and consist of almost water-clear nepheline and sanidine-like felspar often with very irregular outlines, together with a few pleochroic aegirine-augites. The groundmass is trachytic, nepheline being inconspicuous, but it is darkened with small prisms of aegirine-augite and little patches of a cossyrite-like character, accompanied by magnetite grains. Tuffs are conspicuous on the Muira, south of which they soon become the only evidence of volcanic activity among the sedimentaries. On the south side of the Zambesi the exposures along the water's edge show a passage of the Upper Lupata sediments into tuff by gradual increase in the amount of volcanic material, which eventually becomes very coarse and includes huge masses of scoria and "bombs" of large dimensions. Beds of fine white and red sandstone are intercalated amongst the lavas at several points.

Tertiary and other Intrusions.—The intrusions which can with certainty be referred to the Tertiary period are almost entirely confined to the area along the Zambesi. They are characterized by their fine grain, their extraordinary richness in olivine, and the total absence of felspar. On the south side of the river these rocks help to form the Baramwana Hills near Sena, another group near Inyaruka a few miles to the east, and they are scattered along a double line running south-south-east to a point about due east of Muraca, the terminus of the Trans-Zambesia Railway. There are at least two other outcrops near Chupanga. The occurrence north of the river of a rock which was afterwards found to be picrite was noted in 1921, and Mr. van Soelen found that it occurred at two points near Mutarara in January last year. The Inkweri intrusions have already been referred to, but it may be mentioned that an exactly similar rock is intrusive in the (?) Cretaceous sandstones on the left bank of the Muda River south of Vila Machado. No lava flows of Tertiary age have yet been detected. Reference must still be made to the intrusions which form conspicuous groups of hills at three widely separated localities. These include the areas between the Pompue and the Sangadzi Rivers, and that near the Inyadue River from which were derived most of the specimens described by Teale and Campbell Smith. Their descriptions, however, by no means exhaust the variety of types found and their age is too complicated a problem to be discussed here. The other area is one which does not seem to have been previously recognized as including volcanic rocks. This is in the neighbourhood of the Beira and Mashonaland railway near Vila Machado and Siluvu, at which latter locality there are very conspicuous hills of agglomerate and tuff, etc., on both sides of the railway. The nature of the rocks was, however, first determined by a visit made several years ago to some low hills about 4 miles north-west of Vila Machado, which were readily recognized as consisting of volcanic breccia and at once suggested a relationship to the Lupata Volcanics. A section of the freshest variety of the rock to some extent confirmed this, as it revealed the presence of nepheline and untwinned felspar. There is, however, another mineral present, usually represented by natrolite pseudomorphs, which is equally plentiful, and slices from an artificial exposure made last year have proved this to be hauyne or nosean in crystals of characteristic shape and appearance. It is the most conspicuous constituent of some of the rock fragments which contain no recognisable nepheline. It is hoped to examine the rocks of this locality more closely during the present season.

Notes on Some Analyses of Egyptian Metamorphic Rocks (Schists).

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THIS paper gives the results of a series of analyses of typical schists occurring in the Eastern Desert of Egypt. So far as we are aware, no study of this group of metamorphic rocks has as yet been undertaken as regards Egypt itself. Yet this method of attack is essential if any knowledge is to be obtained, not only of their structure and composition, but also of their origin. It must not be forgotten that schists occupy vast areas in south-eastern Egypt, and are also present in Sinai; also among them are included varieties derived from igneous and volcanic rocks as well as from ancient sediments.

One of the most interesting of these occurrences is in the region which contains the ancient emerald (beryl) mines of Sikait, Zabara, and Um Kabu. Here a thick series of mica-, talc-, and hornblende-schists lies between an underlying gneiss and an overlying serpentine. As regards position, Gebel Sikait is in latitude 24° 39′ 55″ N., longitude 34° 48′ 5″ E.

The first four specimens analysed are from this district, and include:—

(1) Typical mica-schist (No. 15613) from the Sikait emerald mine area.

(2) Talc-schist (No. 10327) from Wadi Allawi, in the Zabara district.

(3) Hornblende-schist (No. 10653) from Wadi Sikait.

(4) Quartz-schist (No. 11318) from Wadi Sikait.

With regard to each of these it may be stated :—

(1) The *mica-schist* (No. 15613) forms the main rock containing the beryls (emeralds) for which the Sikait area was famous in Ptolemaic times. The beryls are often enclosed in masses of quartz which are embedded in the schist. The gneiss which underlies it has thin bands of mica, first appearing a little distance from the junction with the schist. These bands occur at more frequent intervals as this junction is approached, till finally the mica-schist proper overlies the gneiss as a thick series. The mica in this schist is phlogopite.

(2) The *talc-schist* (No. 10327) is seen under the microscope to be composed of extremely fine-grained talc, in which are scattered small crystals of magnetite. There is nothing remaining in the mineral structure of the schist to indicate from what type of rock it was originally derived, though a crushed serpentine naturally suggests itself.

(3) The *hornblende-schist* (No. 10653) is a typical member of the Sikait schistose series, alternating with talc-schists and with the beryl-containing mica-schists. An analysis of this schist, which occurs on a large scale at Sikait, was especially desirable in order to try and determine from what type of rock it had originated. The result indicates it as being due to the crushing of a soda-dolerite.

The slide contains a lighter portion in which quartz is more abundant than the hornblende, and plagioclase can be recognized in it. This gives rise to a hornblende-gneiss. There is also a great deal of quartz between the hornblende crystals of the main schist, which quartz we regard as secondary.

(4) The *quartz-schist* (No. 11318) also from Wadi Sikait, is a beautifully banded rock in alternating white and pinkish stripes. Under the microscope it is seen to contain (in addition to the quartz), orthoclase, a little microcline, and a little muscovite. It is therefore a felspathic quartz-schist, and in all probability a crushed granodiorite. Occasionally albite twinning is noted, and the rock might represent a crushed pegmatite.

It is of great interest to note that in the series of schists which forms the range of Gebel Sikait and the surrounding area none is of definitely sedimentary origin, but in all cases they appear to be derived from igneous rocks of granitic, basic, or ultrabasic composition which, alternating with each other, have all undergone crushing of an intense character. We are led to the conclusion that they, with the underlying gneiss, are among the oldest of the rocks occurring in Egypt.

The analyses are as follows :—

The remaining specimens are of the following nature: (5) chlorite-schist (No. 1068) from Wadi El Dagbag (lat. 25° 21′ 30″ north, long. 33° 50′ east); (6) chlorite-schist (No. 15614) from the Sukari district; (7) schist (No. 10673) derived from sandstone at Atiri, Northern Sudan; (8) schist (No. 1078), probably a tuff in

	Mica-Schist from Gebel Sikait.	Talc-Schist from Wadi Allawi.	Hornblende-Schist from Wadi Sikait.			Quartz-Schist from Wadi Sikait.		
	No. 15613	No. 10327	No. 10653			No. 11318.		
			Analysis.	Norm.	%	Analysis.	Norm.	%
SiO_2	45·26	60·64	50·01	Orthoclase	2·23	76·36	Quartz	32·23
Al_2O_3	8·19	·95	13·15	Albite	28·84	13·05	Orthoclase	30·05
Fe_2O_3	2·03	·46	2·36	Anorthite	19·89	·13	Albite	33·42
FeO	5·09	4·52	7·76	Diopside $CaSiO_3$	10·96	·27	Anorthite	2·31
MgO	23·59	28·58	8·42	Diopside $MgSiO_3$	6·89	·37	Corundum	·26
CaO	·54	·13	10·07	Diopside $FeSiO_3$	3·40	·55	Hypersthene $MgSiO_3$	·90
Na_2O	1·53	none	3·40	Hypersthene $MgSiO_3$	7·54	4·00	Hypersthene $FeSiO_3$	·29
K_2O	8·11	none	·39	Hypersthene $FeSiO_3$	3·76	5·12	Magnetite	·23
H_2O +	2·20	4·92	1·69	Olivine $2MgO \cdot SiO_2$	4·45	·18	Ilmenite	·04
H_2O −	·30	·04	·07	Olivine $2FeO \cdot SiO_2$	2·42	·14	Pyrite	·06
CO_2	none	none	·48	Magnetite	3·36	none	Apatite	·17
TiO_2	·08	none	1·35	Ilmenite	2·58	·03	Halite	·01
ZrO_2	trace	none	—	Pyrite	·04	trace	Water	·32
P_2O_5	·05	none	·17	Apatite	·34	none		
Cl	trace	none	trace	Calcite	1·00	·02		100·23
S	·06	·02	·02	Water	1·76	·03		
MnO	·06	·02	·16	Carbon	·30	trace		
SrO	none	none	none			none		
BaO	none	none	none		99·76	trace		
Li_2O	trace	none	trace			trace		
Cr_2O_3	·09	·08	·03			—		
V_2O_3	·02	none	·04			—		
NiO	trace	·17	none			—		
F	5·02	—	—			—		
Carbon	—	—	·30			—		
	102·23	100·53	99·87			100·25		
Less O for F and S	2·14	·01	·01			·01		

origin, from Wadi Shalul; (9) a knotted slate (No. 5478) near Gebel Ethmoi, Eastern Sinai; (10) garnet-bearing schist (No. 4637) west bank at Akasha, Northern Sudan.

The microscopic examination of these schists gives the following results:—

(5) The *chlorite-schist* (No. 1068) was a typical example, being mainly composed of chlorite, in association with talc in fair abundance, and with widely distributed highly refracting granules, in places showing the wedge-shaped forms characteristic of sphene. Fibres of tremolite are also present.

(6) The *chlorite-schist* (No. 15614) from the Sukari district (Gebel Sukari is in latitude 24° 56′ 50″ N., longitude 34° 42′ 50″ E.), is a rock which was noted in the field as a slaty schist, but the analysis has conclusively shown its chloritic nature. The silica content is, however, higher than in No. 1068, this gain being almost entirely at the expense of the alumina.

(7) The *schist* (No. 10673) derived from sandstone at Atiri, North Sudan, was a specimen of one of those nondescript schists to which the term "whetstone" was applied in some of the earlier publications of the Geological Survey of Egypt. The microscopic slide showed this to be a quartz-schist containing both biotite and muscovite, some small garnets also being probably present. Tourmaline, with pleochroism in shades of blue-green, was also recognized. It is probable that this schist, and most of those previously recorded as whetstones, are slightly metamorphosed fine-grained sandstones.

(8) The *schist* (No. 1078) from Wadi Shalul is of special interest, as it would be impossible from the hand-specimen to draw conclusions as to its origin. The microscopic slide at once indicates its clastic nature. In addition to the quartz, there is 30 per cent of albite, the other minerals present being a few shreds of biotite and ferruginous material. The conclusion formed in an examination of this rock, which Dr. J. W. Evans kindly carried out with one of us, was that the schist had in all probability once been a sandy alkaline tuff.

(9) The *knotted slate* (No. 5478) from south-east Sinai is the first stage in the contact metamorphism of a series of sediments by an extensive intrusion of granite. It is a very fine-grained biotite-schist with green chlorite and graphitic patches. Cordierite and garnet may be present, but have not been identified with certainty. The rock is part of the metamorphic sedimentary series in South-East Sinai which has been subjected to contact alteration by intrusive granites. It represents the first stage in this contact metamorphism, and is a characteristic "knotenschiefer", the knots in which are well developed and drawn out.

(10) The *garnet-bearing schist* (No. 4637) from near Akasha, in the Northern Sudan, though so widely separated in space from the

Sinai one just described, is very closely related to it in composition, as shown by the analyses. In the Sudan schist, silica is in greater proportion, and alumina correspondingly reduced in quantity.

The analyses of Nos. 1–2, 4–5, 7–8, are by Dr. Harwood ; Nos. 3, 6, and 9–10 by Mr. H. L. Riley. The results are as follows :—

	Chlorite-Schist from Wadi El Dagbag.	Chlorite-Schist from Sukari Area.			Schist from Atiri, North Sudan.
	No. 1068.	No. 15614.			No. 10673.
		Analysis.	Norm.	%	
SiO_2	36·72	44·91	Anorthite	11·87	89·97
Al_2O_3	13·26	7·28	Corundum	2·95	5·04
Fe_2O_3	·84	1·78	Hypersthene $MgO.SiO_2$	55·04	·88
FeO	8·59	7·62	$FeO.SiO_2$	10·42	·34
MgO	24·19	24·69	Olivine $2MgO.SiO_2$	4·33	·40
CaO	5·35	3·44	$2FeO.SiO_2$	·90	·46
Na_2O	none	trace	Magnetite	2·55	none
K_2O	none	trace	Ilmenite	1·21	1·74
H_2O+	8·27	7·53	Pyrite	·04	·66
H_2O-	·22	·61	Apatite	·23	·12
CO_2	none	·72	Chromite	·07	none
TiO_2	1·64	·62	Calcite	1·60	·20
ZrO_2	—	—		91·21	·02
P_2O_5	·35	·10	Water	8·14	·12
Cl	trace	trace	Carbon	·43	trace
S	none	·02			·02
MnO	·17	·11		99·78	trace
SrO	none	none			none
BaO	none	none			none
Li_2O	none	none			trace
Cr_2O_3	none	·04			—
V_2O_3	·04	·05			—
NiO	·10	trace			—
F	—	—			—
C	—	·43			—
	99·74	99·84			99·97
Less O for S		·01			·01
		99·83			99·96

	Schist from Wadi Shalul.			Knotted Slate, Gebel Ethmoi, Eastern Sinai.	Garnet-bearing Schist from near Akasha, Northern Sudan.
	No. 1078.			No. 5478.	No. 4367.
	Analysis.	Norm.	%		
SiO_2	68·60	Quartz	32·82	57·42	62·82
Al_2O_3	13·82	Orthoclase	10·02	18·02	13·07
Fe_2O_3	1·04	Albite	30·93	3·71	3·83
FeO	2·78	Anorthite	8·84	3·80	3·32
MgO	1·74	Corundum	2·76	3·76	3·54
CaO	3·10	Hypersthene $MgSiO_3$	4·30	1·83	2·19
Na_2O	3·67	Hypersthene $FeSiO_3$	3·51	3·35	3·98
K_2O	1·70	Magnetite	1·62	2·97	2·28
H_2O+	1·63	Ilmenite	·91	2·84	1·91
H_2O-	·13	Pyrite	·06	·62	·54
CO_2	·98	Apatite	·13	·46	·06
TiO_2	·48	Calcite	2·20	·87	·63
ZrO_2	none	Water	1·76	—	—
P_2O_5	·06	Carbon	·43	·32	·45
Cl	trace			trace	trace
S	·03		100·29	·04	·02
MnO	·08			·13	1·23
SrO	none			none	none
BaO	·01			trace	trace
Li_2O	trace			none	none
Cr_2O_3	none			none	—
V_2O_3	·02			·04	—
NiO	—			none	—
C	·43			—	—
F	—			—	—
	100·30			100·14	99·87
Less O	·01			·01	·01
	100·29			100·13	99·86

The knotted slate of Sinai and the garnetiferous schist of Akasha can fairly be classed as originating from shales. For comparison we give the range of the analyses of three brick and tile shales from West Virginia, quoted in vol. iii of the *West Virginia Geological*

Survey, 1906, by G. P. Grimsley, the subject of which is "Clays, Limestones, and Cements" (Table I, p. 26):—

BRICK AND TILE SHALES.

Silica	53·30	to	57·75	per cent.
Alumina	18·16	„	20·17	„
Ferric oxide	1·95	„	7·00	„
Ferrous oxide	0·33	„	4·58	„
Magnesia	1·22	„	2·65	„
Lime	0·22	„	4·89	„
Soda	0·62	„	0·96	„
Potash	2·59	„	3·70	„
Water	0·68	„	2·75	„
Titanium oxide	0·72	„	0·87	„
Phosphoric oxide	0·09	„	0·45	„
Loss on Ignition	5·56	„	7·36	„

As regards River Clays, there is a wide range, as shown by the two extremes given below:—

	River Clay, Weston, West Virginia. %	River Clay, Culloden, West Virginia. %
Silica	75·01	52·89
Alumina	12·15	26·56
Ferric oxide	3·65	4·95
Ferrous oxide	0·23	0·59
Magnesia	0·68	1·38
Lime	1·45	0·48
Soda	0·15	0·20
Potash	1·39	3·12
Water	1·45	1·93
Titanium oxide	0·55	1·00
Phosphoric oxide	trace	trace
Loss on Ignition	3·90	7·34
	100·61	100·44

The above analyses of specimens of schists, though small in number, bring out clearly the great variety in the nature of the rocks from which they originated. Briefly summarizing the results, and stating them in dogmatic form:—

(1) The mica-schist from Gebel Sikait is of uncertain origin.

(2) The talc-schist is probably a serpentine, which has been intensely crushed.

(3) The hornblende-schist is perhaps a crushed soda-dolerite, associated with a hornblende-gneiss.

(4) The quartz-schist is a crushed grandiorite or pegmatite.

(5) and (6) These are chlorite-schists of uncertain origin.

(7) The North Sudan schist is a metamorphosed fine-grained sandstone.

(8) The Wadi Shalul schist is a sandy alkaline tuff.
(9) The knotted slate of East Sinai originated as a clay.
(10) The garnetiferous schist of the North Sudan was also a clay, slightly more sandy than No. 9.

The chemical analyses comprised in this paper have been carried out in the laboratory of the Imperial College of Science and Technology, London, and the authors wish to express their thanks to Professor H. B. Baker for kindly affording the necessary facilities. In connection with the chemical work an unexpected difficulty occurred in the analysis of the mica schist No. 15613, a total of only 98 per cent being obtained, despite several repetitions. No additional constituent could be found, and the error was eventually traced to the alkali determination. Owing to the very flaky nature of the rock, it was found necessary when using the method of Lawrence Smith to increase the ratio of rock, ammonium chloride, and calcium carbonate from the usual 1 : 1 : 8 to 1 : $1\frac{1}{2}$: 12, and also to prolong the time of heating (after expulsion of the ammonium salts) to 2 hours. Experiments carried out under these conditions gave 2 per cent more alkali than was obtained by following out the usual method, and it is recommended in consequence that in carrying out alkali determinations on rocks of a soft flaky character the usual procedure should be modified as above.

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On the Occurrence of Iron-rich Cordierite in Aberdeenshire.

By H. H. READ.

INTRODUCTION.

IN my account[1] of the petrology of the Arnage district of Aberdeenshire, there appeared a description, figure, and analysis of a cordierite-spinel-hornfels from Gallowhill Brae, Arnage. This rock is composed almost entirely of cordierite, with only an accessory amount of spinel, biotite, and plagioclase. On the assumption that the analysis represented the composition of the sliced material, it was pointed out that in the cordierite of this rock, iron-oxides must replace much of the alumina and magnesia of normal cordierite.

In order to investigate further the probable constitution of the Arnage cordierite, apparently identical material has been examined and analysed. The result of these later analyses carried out independently by Mr. W. H. Herdsman and Mr. E. G. Radley has been to show that the original analysis does not represent the true composition of the rock in question. In the following discussion the original analysis will therefore be disregarded.

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[1] H. H. Read, "The Petrology of the Arnage District (Aberdeenshire)": *Q.J.G.S.*, lxxix, 1923, pp. 476–8, fig. 6*b*. The analysis is also given in "Summary of Progress for 1923": *Mem. Geol. Surv.*, 1924, p. 134.

THE CORDIERITE-SPINEL-HORNFELS.

The dark blue, greasy-looking hornfels is seen in thin section to be made up of some 90 per cent cordierite, the remainder of the rock being plagioclase, spinel and biotite. Separation and measurement of the amount of spinel and biotite gave 5 per cent by weight; of this possibly four-fifths is spinel. The plagioclase is somewhat irregular in distribution, both in the same slice and in different slices, and on account of this no determination of its proportion has been made, but it can be estimated at about 5 per cent. The rock has been analysed by Mr. W. H. Herdsman, with the result given in column A in the Table below.

I am indebted also to Mr. E. G. Radley for an independent analysis of this rock, the results of which are set out in column A1.

	A	A 1	B	C	D	E	
SiO_2	44·05	45·52	48·35	44·52	49·15	39·05	SiO_2
Al_2O_3	31·70	29·40	28·29	28·63	31·84	29·07	Al_2O_3
Fe_2O_3	trace	3·61	1·67	1·78	2·88	0·51	Fe_2O_3
FeO	14·65	11·82	10·86	10·75	11·49	24·97	FeO
MgO	5·04	4·14	3·54	4·14	0·55	0·34	MgO
CaO	0·40	0·93	1·35	1·25	4·30	2·22	CaO
Na_2O	trace	0·63	1·84	3·21	—	1·36	Na_2O
K_2O	trace	0·30	2·28	2·69	—	0·95	K_2O
H_2O +	1·30	1·39	0·76	0·45	0·06	0·96	H_2O +
H_2O —	0·20	0·02	0·04	0·20		0·07	H_2O —
CO_2	nil	—	nil	nil		—	CO_2
TiO_2	2·20	2·04	0·60	2·05	—	0·03	TiO_2
P_2O_5	nil	0·06	0·05	0·03	—	0·06	P_2O_5
SO_3	—	—	—	trace	—	—	SO_3
S	trace	—	0·07	0·27	—	0·02	S
MnO	0·38	0·33	0·34	trace	—	0·36	MnO
CoNiO	nil	0·02	trace	trace	—	—	CoNiO
BaO	—	0·01	—	—	—	—	BaO
	99·97	100·22	100·04	99·97	100·27	99·97	

A. *Cordierite-spinel-hornfels*, Gallowhill Brae, Arnage, Aberdeenshire. *Anal.*, W. H. Herdsman.

A 1. *Cordierite-spinel-hornfels*, Gallowhill Brae, Arnage, Aberdeenshire. *Anal.*, E. G. Radley.

B. *Cordierite-spinel-hornfels*, Creag na-h Iolaire, Glen Lednock, Perthshire. *Anal.*, C. E. Tilley, *Q.J.G.S.*, lxxx, 1924, p. 52.

C. *Cordierite-spinel-hornfels*, Craig More, Comrie, Perthshire. *Anal.*, C. E. Tilley, loc. cit., p. 53.

D. *Cordierite-spinel-ilmenite-glass rock*, Gunung Seputan Volcano, Menado, North Celebes, H. Bücking, *Ber. d. Senckenbergischen naturf. Gesell., Frankfurt a. M.*, 1900, quoted in *Referate, Neues Jahrb.*, 1901, ii, pp. 72–3.

E. *Cordierite-bearing Para-lava* (Fused Ferruginous Shale ?), Bermo, Bokaro Coalfield, India. *Anal.*, C. S. Fawcitt, in L. L. Fermor, "Preliminary Note on the Burning of Coal Seams at the Outcrop": *Trans. Min. Geol. Inst. India*, xii, pp. 55–6.

Inspection of the analyses of the Aberdeenshire hornfels shows at once that the cordierite must be an iron-rich variety. C. E. Tilley[1] came to the same conclusion for the cordierite of the Perthshire cordierite-spinel-hornfelses, whose analyses are given in columns B and C of the Table above. Allowing for the much greater proportion of cordierite in the Arnage rock, the three analysed Scottish cordierite-spinel-hornfelses are seen to be remarkably similar. It may be noted that all three come from the innermost zone of hornfelses. Two other comparisons of interest may be made. H. Bücking[2] has described a bomb from a volcano in North Celebes that consists essentially of cordierite, with scanty glass, a small amount of pleonaste and possibly ilmenite. An analysis of this rock is given in column D. Such an analysis would indicate that the cordierite must be extremely rich in iron. Bücking came to the came conclusion for the cordierite of a vitrified sandstone from Germany that consisted of 50 per cent cordierite, 10 per cent iron-spinel, and 40 per cent. glass, the analysis showing only enough magnesia to give 14 per cent of the magnesia-iron-cordierite of Rammelsberg's formula. A final comparison may be made with the para-lava[3] of analysis E. This rock results from the melting of an iron-rich shale by the burning of an underlying coal-seam. Dr. L. L. Fermor, of the Geological Survey of India, has kindly supplied me with information regarding this rock. He finds that comparison of the amounts of magnesia in the analysis and of the cordierite in the rock indicates that the cordierite must be iron-rich.[4]

THE CORDIERITE.

In order to obtain a closer approximation to the composition of the Arnage cordierite and to afford a general check on the analyses of the complete rock, the spinel and biotite were separated and the remainder analysed. The crushed rock was ground fine till no composite grains of spinel and cordierite were observed. The material was then centrifuged in bromoform, the lighter fraction, consisting of cordierite and plagioclase, was collected, washed, dried, and analysed. Since the amount of ferric oxide is so small, the fine grinding of the rock that was found necessary cannot have affected the state of oxidation of some of the iron and, in any case, if this has happened, it has been consistent for both rock and mineral. The analysis was performed by Mr. W. H. Herdsman, who kindly repeated the determination of the first five oxides. Inspection of the analysed material showed that a minute portion of spinel dust still remained in the sample. The cordierite was perfectly fresh.

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[1] C. E. Tilley, "Contact-Metamorphism in the Comrie Area of the Perthshire Highland": *Q.J.G.S.*, lxxx, 1924, pp. 52–3.

[2] H. Bücking, "Cordierite von Nord-Celebes und aus den sogen. verglasten Sandsteinen Mitteldeutschlands": *Ber. d. Senckenbergischen naturf. Ges. in Frankfurt a. M.*, 1900. Abstract by O. Mügge in *Neues Jahrb.*, 1901, ii, pp. 72–3.

[3] L. L. Fermor, "Preliminary Note on the Burning of Coal Seams at the Outcrop": *Trans. Min. Geol. Inst. India*, xii, pp. 50–9.

[4] Cf. L. L. Fermor in the Discussion to C. E. Tilley, loc. cit., pp. 70–1.

	F.
SiO_2 . .	45·70
Al_2O_3 . .	32·64
Fe_2O_3 . .	0·14
FeO . .	12·98
MgO . .	5·35
CaO . .	0·80
Na_2O . .	0·35
K_2O . .	trace
H_2O + . .	1·37
H_2O — . .	0·24
CO_2. . .	nil
TiO_2 . .	trace
P_2O_5 . .	nil
S . . .	trace
MnO . .	0·33
	99·90

F. Cordierite-plagioclase residue from cordierite-plagioclase-spinel-biotite-hornfels, Gallowhill Brae, Arnage.

Reckoning the soda of the above analysis as albite, the lime as anorthite, and removing this plagioclase and then recalculating the residue to 100 per cent, we obtain the calculated composition of the Arnage cordierite as given in Column G below. This may be compared with the theoretical compositions (H and J) deduced by Farrington and Clarke, which are in accord with analyses of the classic Guilford, Haddam, and Orijärvi cordierites.

	G.	H.	J.	K.
SiO_2 . .	45·24	49·40	49·26	48·58
Al_2O_3 .	33·00	33·60	33·50	32·44
Fe_2O_3 .	0·15	—	—	3·15
FeO . .	14·00	5·27	5·91	9·17
MnO .	0·36	—	—	trace
MgO . .	5·77	10·25	9·85	6·63
H_2O . .	1·48	1·48	1·48	—
	100·00	100·00	100·00	99·97

G. *Cordierite*, calculated, Arnage.

H. *Cordierite*, Farrington's theoretical, as $H_2O.4(MgFe)O.4Al_2O_3.10SiO_2$, with MgO : FeO = 7 : 2. O. C. Farrington, *Amer. Journ. Sci.*, lxiii, 1892, p. 15.

J. *Cordierite*, Clarke's theoretical, F. W. Clarke, *Bull. U.S.G.S.*, 588, 1914, p. 79.

K. *Cordierite*, Cabo de Gata, A. Osann, *Z. d. geol. Ges.*, lxx, 1888, p. 704.

It is at once apparent that the Arnage cordierite is extremely rich in iron. Among modern analyses of cordierites it is approached nearest by that of the Cabo de Gata material, given in Column K above. The defect in this estimation of the Arnage cordierite is the low silica, a defect that cannot be accounted for by possible spinel impurity.

In order to bring out the abnormal iron-content of the Arnage cordierite, there are tabulated below the ratios of the molecular proportions of FeO and MgO in representative analysed cordierites. For this purpose, Fe_2O_3 has been added to FeO, and MnO to MgO.

Locality.	FeO : MgO	Analyst and source.
Arnage (calculated)	1·32	
Cabo de Gata .	0·89	A. Osann, *Z. d. geol. Ges.*, lxx, 1888, p. 704.
Travancore . .	0·72	I. C. Chacko, GEOL. MAG., 1916, p. 463.
Japan . . .	0·56	Shimidsu, *Journ. Imp. Univ. Tokyo*, iii, 1890, p. 325.
Madura, India .	0·47	M. S. Krishnan, *Min. Mag.*, xx, 1924, p. 249.
Träskbole, Finland	0·39	P. Eskola, *Bull. Com. Géol. Finlande*, xl, 1914, p. 172.
Guilford, Conn. .	0·29	O. C. Farrington, *Amer. Journ. Sçi.*, lxiii, 1892, p. 14.
Haddam, Conn. .	0·28	O. C. Farrington, loc. cit., p. 14.
Orijärvi, Finland .	0·25	Dittrich, *Trav. Soc. Imp. Nat. St. Petersbourg*, xxxvi, 1912, p. 213.

The Arnage material is the only cordierite in which the FeO:MgO ratio exceeds unity. The question arises as to whether this value can be confirmed in any measure from the analyses of the total cordierite-spinel-hornfels. This rock contains 5 per cent of spinel and biotite, of which four-fifths is reckoned to be spinel. It may reasonably be assumed that the spinel has the composition of the analysed Mull spinel[1]; the two spinels are much alike in characters and associates. Further, the biotite most probably closely resembles the hornfels-biotite analysed by P. E. Jannasch.[2] If 4 per cent spinel of the Mull composition and 1 per cent of Jannasch's biotite are deducted from the analysis A of the Arnage cordierite-spinel-hornfels, it is found that the FeO:MgO ratio of the remainder, in which only the cordierite is concerned, is about 1·63. Using the second analysis, A1, and leaving Fe_2O_3 out of account, we obtain the figure 1·61. It is substantiated, therefore, that the ferrous oxide : magnesia ratio in the Arnage cordierite is greater than unity.

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[1] Mull Memoir, 1924, p. 34.

[2] *Nyt Mag. f. Naturv.*, xxx, 1886, p. 318.

This conclusion raises questions of considerable interest with regard to certain mineral parageneses in metamorphic rocks. For instance, it has been stated by P. Eskola [1] that—

"The series of mixtures of corresponding magnesium and ferrous compounds is continuous in the group of pyroxenes, amphiboles, and biotite, but interrupted in the cordierites, with a maximum molecular quantity of the ferrous compound of approximately 50 per cent."

Further, Eskola [2] goes on to remark that :—

"It seems apparent that it is the ratio FeO:MgO that decides which is formed, almandite or cordierite + anthophyllite. An application of the phase-rule leads directly to the conclusion that it is the imperfect mixability of the ferrous and magnesium compounds that causes the appearance of the almandite. MgO and FeO, in a rock being too rich in the latter to form cordierite, behave as two independent components and this system contains one component more than is generally the rule. Therefore a new phase (almandite) appears without causing any of the others to disappear."

H. Backlund,[3] in his discussion of the Taimyr garnet-cordierite-gneiss, subscribes to Eskola's view of the limited replacement of magnesia by ferrous iron in cordierite, with the resultant appearance of the new phase, almandine, in the iron-rich rocks.

It has now been shown, however, that the limit of replacement by iron-oxide advanced by Eskola has been exceeded. This is certain for the Arnage cordierite and extremely probable for the Comrie cordierite, both formed under the physical conditions of xenolithic contact or of the inner zone of hornfelses. Further chemical study of cordierites from iron-rich rocks is needed in order to examine the question as to whether any discontinuity whatever exists in a series varying from magnesia-cordierite to iron-cordierite. On this depends the application of the phase-rule to the rocks concerned.

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[1] P. Eskola, "Om Sambandet mellan Kemisk och Mineralogisk Sammansattning hos Orijärvitraktens Metamorpha Bergarter": *Bull. Com. Géol. Finlande*, No. 44, p. 122.

[2] Loc. cit., p. 123.

[3] H. Backlund, "Petrogenetische Studien an Taimyrgesteinen": *G.F.F.*, xl, 1918, pp. 126–7.

Further Evidence for the Contemporaneous Age of the Mourne Granite and the Rhyolites of Tardree in Northern Ireland.

By Herbert P. T. Rohleder, Dr.Phil., Ph.D., D.I.C., F.G.S.,
Broken Hill, Northern Rhodesia.

During the second half of the nineteenth century, when the district was mapped by the Geological Survey, the acid rocks (rhyolites) near Antrim town at Tardree Cottage, Scolboa, and Sandy Braes were regarded as older than both basalt sets, the lower and the upper basalts of Co. Antrim (1).

Later on McHenry (2) obtained evidence at Templepatrick quarry that the rhyolite had been erupted in the form of a laccolith into the lower basalt series, but that it was overlain by subsequently decomposed boles and lithomarge and succeeded by the upper basalt series. He says: "The rhyolite, therefore, may be regarded as, so to speak, of mid-basaltic age, i.e. occurring between the period of the lower and upper basalts. I may here mention that I regard it as highly probable that the granite of the Mourne Mountains is contemporaneous with the rhyolite of Co. Antrim."

This view is supported by the following two observations of the author:—

(1) When studying the geology of the Mourne granite mass the author gave special attention to the jointing phenomena (5). Over 3,000 measurements at fifty different localities yielded the norm

16° 50° 94° 149°

i.e. a set of principal joints in approximately north-south and east-west direction, and a set of diagonal joints intersecting the latter.

As the new rhyolite quarry at Tardree Mountain shows very pronounced jointing the author decided last summer to apply the same system of calculating the average directions of joints as he previously had done in the Mourne Mountains. All in all, 117 measurements were taken and the result of the calculation was:—

14° 51° 94° 147°

The startling similarity of these figures seems to indicate that the conditions of cooling in the Mourne area and Tardree were analogous, a fact which is in favour of the theory of contemporaneous age.

As regards the age of these joints, there is no difficulty in coming to a definite conclusion:—

All the pregranitic rocks, in particular the "older" basalt dykes which are cut off by the Mourne granite mass, exhibit this jointing. Also all the granitic varieties of the Mourne mass, as well as the acid dyke sequences (aplites, "eurites," quartz-porphyries), show the jointing. And in the neighbouring Co. Antrim these systems of joints have been traced by the author in the lower (mostly coarse grained) series of basalt at many localities, e.g. Slemish Mountain, between Bengore Head and Portmoon, Fairhead, Portrush; in no instance, however, has this jointing been observed in the younger, "upper," basalt series.

One is, therefore, fully justified in dating the jointing at the latest stage of the granitic phase, probably at the interval of volcanic quiescence between the intrusion of the granite and the following outflow of younger ("upper") basalts.

(2) The great similarity in the chemical composition of the Tardree rhyolites and the Mourne granite has been pointed out by McHenry (3). The same author stated "that the Mourne granite is often very trachytic in appearance, frequently resembling some of the varieties of the Tardree rock."

The term "trachytic" was probably due to A. von Lasaulx's examination of the Tardree rock, as he called it "Quarzsanidintrachyt" (6, 7). This term, has, however, been replaced by rhyolite, as Grenville A. J. Cole (4) believed "that the term 'trachyte' could no longer be used in connection with any post-Cretaceous rock in County Antrim".

In the Tardree area we have all the links from a real rhyolite, i.e. a porphyritic-effusive type, to volcanic glass, consisting of grey, black, and greenish obsidian, sometimes perlitic, rarely spherulitic, and always containing porphyritic quartz and felspars.

The greatest similarity is to be found when comparing certain acid rocks (quartz-porphyries) of the Mournes with the porphyritic types of Tardree; in particular the vein occurrences near the Spellack (Mourne Mountains) with the pink rhyolitic material near Tardree Inn, which is exposed in a small quarry and is excavated for use on the walks of local demesnes, as it breaks up easily under the hammer. The structure, especially the rounded and much corroded shapes of the quartz phenocrysts in a very fine groundmass seem to indicate that here we have the greatest analogy between the two varieties of acid rocks.

Thus one seems justified not only in regarding the Tardree effusive rocks as of interbasaltic age, i.e. contemporaneous with the Mourne granite, but actually as offshoots of the late granitic intrusions, originating from the same magma reservoir. Where exactly the Tardree rhyolites should be placed in the course of the intrusive sequence of the granite mass of the Mourne Mountains is shown in the table on p. 555 :—

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(1) *Sheet Memoir*, Geol. Survey of Ireland.

(2) A. McHenry. "Sketch of the Geology of Co. Antrim": *Proc. Geol. Assoc.*, 1895.

(3) A. McHenry. "On the age of the trachytic rocks of Antrim": Geol. Mag., 1895.

(4) Grenville A. J. Cole. "The Volcano of Tardree": Geol. Mag., 1895.

CORRELATION TABLE.

	BASALTIC DISTRICT OF CO. ANTRIM.	NEIGHBOURHOOD OF TARDREE.	MOURNE MOUNTAINS.
Younger basaltic period.	Younger ("upper") basalt series.	Younger ("upper") basalt.	Postgranitic basalt dykes intersecting the Mourne granite mass.
Interbasaltic period.	Subaërial alteration of basalts to bauxitic and lateritic material.	Rhyolites partly altered by subaërial processes to bauxitic material.	Plutonic quietness.
	Process of jointing.	Process of jointing: slight alterations by pneumatolytic-hydrothermal processes.	Process of jointing (post-plutonic phase). Hydrothermal action. Formation of basic segregation veins by pneumatolytic action. Aplitic veins in granite.
		Extrusion of rhyolites (tuff ?).	Quartz-porphyry dykes in Mourne Mountains. = "Eurite" dykes in neighbouring country.
	Volcanic quietness. Subaërial alteration of basalts to bauxitic and lateritic material.	Volcanic quietness.	Short phase of quietness. Granite Intrusion. { 4. Pink Variety (G4). 3. Aplitic Variety (G3). 2. Quartzose Variety (G2). 1. Felspathic Variety (G1 and G1^1). } J. E. Ritchie's nomenclature.
Older basaltic period.	Older ("lower") basalt series.	Older ("lower") basalt.	Pregranitic basalt dykes cut off by granite.

(5) H. P. T. Rohleder. "Ergebnisse geologisch-petrographischer Untersuchungen im Granitmassiv des Mourne Gebirges (Grafschaft Down, Nordirland)": *Neues Jahrbuch für Geologie*, 1929; and "A tectonic analysis of the Mourne Mts. (Co. Down)": *Proc. Royal Irish Academy*, 1929.
(6) A. von Lasaulx. "Petrographische Skizzen aus Irland": *Tschermaks Min. & Petrogr. Mitt.*, Bd. i, 1878.
(7) A. von Lasaulx. "Quarztrachyte of Tardree": *Journ. Geol. Soc. Ireland*, 1880.
(8) J. E. Ritchie. "The structural relations of the Mourne granites (Northern Ireland)": *Quart. Journ. Geol. Soc.*, vol. lxxxiii, pt. v, 1928.

REVIEWS.

Ball Clays. By A. Scott. Spec. Rep. Min. Res. Great Britain, vol. xxxi, *Mem. Geological Survey*, pp. v + 73, with 7 figures. H.M. Stationery Office, 1929. Price 2*s*. 6*d*.

THE name commonly given to the clays of this group has no particular relation to their properties, but refers solely to the method of working usually employed. Geologically they are simply transported china-clay, mostly laid down in lake basins of Tertiary date. The properties are therefore somewhat similar to those of china-clay in situ, but ball clays possess a higher degree of plasticity, which is of value in certain ceramic processes. The only deposits in this country are in the south-west of England, comprising the well-known Bovey Tracy lake basin; another similar one near Torrington, and certain beds near Wareham and Poole, of Lower Bagshot age. It seems to be now established that the Bovey Tracy beds are Miocene and the Torrington basin is presumably of the same date. In all cases the clay is certainly derived from the Dartmoor granite.

This admirable memoir seems to contain pretty well all that could be said on the subject. There is not much reference to the operations of the pre-War German company at Bovey Tracy, as to which some humorous details appeared in an earlier volume of the same series. There is probably scope for palaeobotanical work in the Torrington basin, about which little appears to be known geologically. Specimens of clay and lignite in the economic collection in the Sedgwick Museum at Cambridge from this locality are quite indistinguishable from those collected at Bovey Tracy.

Patterns for a Series of Block Models, Second Series. By F. Smithson. London: Thomas Murby, 1929. Price 1*s*. 6*d*.

THIS second series carries the models of geological structures into the realm of igneous intrusion and although such may lend themselves to models with an horizontal surface it is felt that any further advance in model making must have a diversified topography. This however cannot be done on printed papers.

GEOLOGIE EN GEOHYDROLOGIE VAN HET EILAND CURAÇAO. By G. J. H. MOLENGRAAFF. pp. xii + 126, with 24 plates, and maps, sections and plans. J. Waltman, jun., Delft, 1929.

A PROPER understanding of the geology of the West Indian islands is evidently a necessary factor in the broader problems of earth tectonics, in view of the conflicting ideas that have been put forward as to the relation of the Antillean arcs to the major fold-lines of the earth. The volume under review is to be welcomed as a notable contribution to this subject, as it contains a special chapter devoted to the tectonics of the West Indies, with a useful map. Periods of folding in Curaçao are recognized as Hercynian, Laramide and Alpine. The oldest rocks so far known are volcanic, associated with radiolarites and greywackes, perhaps Cretaceous, followed by the Knip series with tuffs, and then by the Upper Cretaceous Seroe Teintje limestone. During the Eocene folding there were intrusions of quartz-diorite, diorite-porphyrite and dolerite. The upper part of the Tertiary is absent, and the story ends with a rather complicated Pleistocene history, with conglomerates, limestones and reef-limestones gently folded and uplifted. A description is given of Upper Cretaceous echinoids, and of the petrology of the rocks. The last twenty-seven pages of the book are devoted to an account of the climate and hydrology of the island.

GEOLOGICAL NOMENCLATOR. Edited by L. RUTTEN. pp. viii + 339, with 58 illustrations. The Hague: G. Naeff, 1929. Price 21 guilders.

THIS book, which is published by the Geologisch Mijnbouwkundig Genootschap voor Nederland en Kolonien, is a geological dictionary in four languages, compiled by a number of well-known geologists. The arrangement is in eight sections according to subjects, and the printing in columns. It is a drawback for English users that the first column and the definitions are in Dutch, but a very copious index-system will enable the equivalents of any terms in English, French, German or Dutch to be found without trouble. The book will be of great service to those who have to read much geological literature in the languages named.

CORRESPONDENCE.

THE DEINOSAUR DEPOSITS AT TENDAGURU, TANGANYIKA TERRITORY.

Sir,—Dr. Kitchin's paper in the Geological Magazine for May, 1929, on the vexed question of the age of the Deinosaurs at Tendaguru, sums up, I think, the whole of the palaeontological evidence at present published. The problem to be solved is the age of the *Smeei* beds, an affair for experts who have specialized in the Upper Jurassic and Lower Cretaceous faunas. As, however, I was in Tendaguru for about seven months in 1927 and for a few weeks in 1928 I may perhaps be allowed to add some comments from the point of view of the field-geologist. My contribution to the *Natural History Magazine* was intended to be nothing but a popular article. Later, I hope to publish such observations as I was able to make in more detail.

The almost horizontal attitude of the beds, the absence of contour maps and of any dominant bed such as a well-marked limestone or conglomerate, make it difficult to say which part of the series we may be in, e.g. whether any given bone deposit belongs to the Upper or Middle Saurian bed, supposing they are indeed distinct and separate. Also, although the strata are nearly horizontal, they are not quite, but are probably undulating with dips of one or two degrees, not easy to measure on the ground, especially in pits, where false-bedding is ever to be suspected. Failing the proximity of the *Smeei* fauna, or without definite evidence, it appears to me doubtfully wise unhesitatingly to accept the vertebrate fossils from certain pits as belonging to one of the Saurian horizons, as shown in the sketch-map, " Die Grabungsstellen am Tendaguru ", when by slightly shifting a geological boundary or by inserting a small dip the bones could be placed in the other, according to German authors, of considerably greater or less antiquity. There are minor difficulties as regards thickness. The occurrence of *Trigonia smeei* through more than 20 m. of consecutive sands and sandy clays appears evident in the Maimbwi Valley. In the stream section, the banks are high and covered with dense vegetation, the *Smeei* beds seem to pass downwards into some representative of the *Nerinaea* bed with no indication of an intercalated bone-bed, except for a small fragment embedded in the sandstones. In the Mtapaia-Kinjele sections, the thickness between two sandstones full of *T. smeei* and abundant corals was judged by eye (in the absence of a level) to be about 45 m.

One of these *Smeei* beds was slightly above the German locality " aa " or " Fundort 15a ", while close at hand were slabs of rock containing very many *Nerinaea* (and *Nerinella*, for field purposes the writer did not distinguish). A little more than half a mile away, *Nerinaea* also occurs in quantity at a horizon a little lower than "Fundort 15a". In the midst of these marine beds was found the skeleton of a deinosaur. At Nguruwe, S.W. of the Hill, a very well-marked reptile bed is intercalated between two sandstones containing *T. smeei* and the usual associated corals, etc. Close to Nautope, the village is now non-existent, a mixed *Nerinaea* and *Smeei* fauna was noted, though poorly developed.

In the geological map by Dr. Hennig an east and west trending trough, the Niongala Schölle, cross-faulted on the east, embraces a portion of the Mbemkuru Valley and is shown as bringing the Middle Saurian beds on the South against the *Schwarzi* beds occupying the trough. As being in the midst of strata so very slightly disturbed, the proof of such a structure would need to be conclusive. Several days' work at Niongala gave, in the writer's opinion, no evidence for the southern fault; the northern part of the area was not examined. The characteristic deposit of the trough is alluvium, not shown on Hennig's map. Three "*Schwarzi*" localities were examined in this area; one, according to Dr. Spath, Aptian, probably falls within the faults as drawn; the others are some distance to the south. Nautope, in the middle of the trough, has been mentioned.

From this examination it appeared to the writer that erosion of the Upper Saurian and *Smeei* beds had probably taken place without faulting, and that subsidence had subsequently allowed for the deposition of the Schwarzi beds. Such a disconformity is in keeping with the vertical oscillatory movements of the East African coast. In the majority of cases the invertebrate fossils lie scattered or partly embedded along the slopes of hillsides or on undulating ground; otherwise, strewn along the dry stream beds. Exceptions are usual in the case of *T. smeei*, which now and again occurs in quantity embedded in rough sandstones, as in the Maimbwi and Tingutinguti Rivers. West of Niongala, *T. schwarzi* and other *Trigoniae* litter the ground, clearly not far from the original places of burial, but unfortunately in many instances (Matapua) the shells occur on a steep hill-side, lying near the surface, and many at least have travelled some distance from their original sites. Exact zoning is thus often rendered impossible. The writer formed the definite conclusion in the field that the *Schwarzi* beds are distinctly marked off from the lower faunas. The *Nerinaea* beds were examined in three localities W. of Tendaguru Hill and in the Kindope Valley, the *Smeei* beds at nine localities, the *Schwarzi* beds at three localities near Niongala and at five others widely scattered, but some of these were very unsatisfactory in results.

Collections from all these were sent to the Natural History Museum. In view of these facts, and in order to attempt some conclusions, the writer ran lines of levels from a datum point below the Hill to various invertebrate and vertebrate localities in the immediate neighbourhood and placed these beds in a vertical section. Four localities showing the *Smeei* fauna were included. Failing extensive pit-digging for such purely structural purposes, the strata were assumed to be horizontal, an assumption to which objection has already been raised, but distances were small (the longest 1¼ miles) and minor oscillations tend to cancel one another, hence it is believed that the section shows conditions nearer the truth than the hard and fast classification of our predecessors depending on definite periods of marine and estuarine deposition.

Owing to fever and other matters this work finished earlier than had been hoped, and the Expedition temporarily terminated operations at the end of 1928.

The following are then tentative results :—

(1) That the *Nerinaea* bed is a lower and local phase only of the *Smeei* beds.

(2) That in ascending from the *Nerinaea* bed to the top of the Upper Saurian bed, estuarine conditions became increasingly prevalent until finally marine deposition ceased, or almost ceased, and that during the part of the sequence represented by the German *Smeei* bed fresh or brackish water conditions alternated with local episodes ; in fact the two co-existed in adjacent neighbourhoods. That is, the two Saurian beds of our predecessors are one.

(3) That a disconformity occurs above the so-called Upper Saurian bed of an importance which palaeontologists must decide.

It is worthy to mention that, although constantly looked for, no ammonites were found in the *Smeei* beds, except doubtful and very large specimens N.N.W. of Matapua, the German localities 27 and 27a. Ammonites were, however, found by Mr. Cutler in a trench named " 2x " cut in the middle of pits known as " M2 ", and without question in situ. Belemnites were also found by me at two or more horizons obviously buried with the very numerous deinosaur bones and the few pterosaurian bones, which made this locality one of the most interesting in Tendaguru.

JOHN PARKINSON.

UFIPA HIGHLANDS,
TANGANYIKA TERRITORY.
14*th June*, 1929.

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